

METHOD AND CIRCUIT FOR LIMITING A PUMPED VOLTAGE

TECHNICAL FIELD

The present invention relates generally to voltage generation circuits, and, more particularly, to controlling the voltage developed by a voltage generation circuit.

5 BACKGROUND OF THE INVENTION

Voltage generation circuits are utilized in many integrated circuits to generate voltages required for proper operation of the integrated circuit. For example, in a semiconductor memory device such as a dynamic random access memory (DRAM) a supply voltage VCC is applied to the device and a voltage generation circuit within the
10 memory device generates a pumped voltage VCCP having a value greater than the supply voltage. In a DRAM, the pumped voltage VCCP is utilized, for example, in driving word lines of a memory-cell array when accessing rows of memory cells contained in the array, as will be appreciated by those skilled in the art. The value of the pumped voltage VCCP is greater than the supply voltage VCC so that capacitors in the memory cells may be charged
15 to the supply voltage, as will once again be understood by those skilled in the art.

Figure 1 is a functional block diagram and schematic illustrating a conventional voltage generation circuit 100 that may be utilized in a DRAM to generate a pumped voltage VCCP having a value greater than an applied supply voltage VCC. The voltage generation circuit 100 includes an oscillator 102 that generates an oscillator signal
20 OSC in response to an enable signal EN applied by a Schmitt Trigger comparator 104. The oscillator 102 clocks the OSC signal when the EN signal is active and does not clock the OSC signal when the EN signal is inactive, instead maintaining the OSC signal either high or low. The OSC signal is applied to clock a charge pump circuit 106 which, in response to the OSC signal, generates the pumped voltage VCCP. More specifically, when the OSC
25 signal clocks the charge pump circuit 106, the circuit turns ON and charges a load capacitor 108 to thereby develop the pumped voltage VCCP and drive a load resistance 109. When

the OSC signal does not clock the charge pump circuit 106, the circuit turns OFF and stops charging the load capacitor 108. The detailed operation and circuitry for forming the oscillator 102 and charge pump circuit 106 are well understood by those skilled in the art, and thus, for the sake of brevity, these components will not be described in further detail.

5 The pumped voltage VCCP is applied through a diode-coupled PMOS transistor 110 and a level shifting circuit 112 to develop a pump feedback voltage VPF that is applied to a first input of the Schmitt Trigger comparator 104. The diode-coupled transistor 110 functions as a level shifter to reduce the value of the pumped voltage VCCP and ensure proper common-mode operation of the Schmitt Trigger comparator 104, as will
10 be appreciated by those skilled in the art. The level shifting circuit 112 reduces the voltage from the diode-coupled transistor 110 by an offset voltage VOFF, which has a value determined, in part, by the desired value of the pump feedback voltage VPF. A current source 114 causes a desired current to flow through the diode-coupled transistor 110 and level shifting circuit 112 so that the feedback voltage VPF having the desired value is
15 developed on the first input of the Schmitt Trigger comparator 104. A second input of the Schmitt Trigger comparator 104 receives a reference voltage VREF that is developed by a diode-coupled PMOS transistor 116 and a current source 118 coupled in series between the supply voltage VCC and ground. The diode-coupled transistor 116 functions as a level shifter to reduce the value of the supply voltage VCC and provide for proper common
20 mode operation of the Schmitt Trigger comparator 104, as will be appreciated by those skilled in the art. The current source 118 causes a desired current to flow through the diode-coupled transistor 116 to develop the reference voltage VREF on the second input of the Schmitt Trigger comparator 104.

 The voltage generation circuit 100 further includes over voltage protection
25 components that attempt to limit the value of the pumped voltage VCCP as the supply voltage VCC increases. The overvoltage protection components include an overvoltage detector 120 that monitors the supply voltage VCC and develops an overvoltage signal OV having a value that is a function of the monitored supply voltage. The overvoltage signal

- OV is applied to an NMOS transistor 122 that is connected in series with a current source 124 and coupled between the second input of the Schmitt Trigger comparator 104 and ground. When the overvoltage signal OV has a sufficient magnitude, the transistor 122 turns ON causing current to flow through the transistor and current source 124 to ground.
- 5 The transistor 122 and current source 124 together form a current limiting circuit 126 that operates during an overvoltage mode of the circuit 100, as will be described in more detail below. The overvoltage signal OV is further applied to a voltage clamping circuit 128 formed by an NMOS transistor 130 and diode-coupled transistor 132 coupled between the output of the charge pump 106 and the supply voltage VCC. When the overvoltage signal
- 10 OV has a sufficient magnitude, the transistor 130 turns ON allowing current to flow through the diode-coupled transistor 132 and transistor to the supply voltage VCC to thereby clamp the pumped voltage VCCP.

During normal operation of the voltage generation circuit 100, the supply voltage VCC has a predetermined value and the overvoltage detector 120 drives the

15 overvoltage signal OV sufficiently low to turn OFF the transistors 122 and 130. Thus, during normal operation the current limiting circuit 126 and clamping circuit 128 do not affect operation of the voltage generation circuit 100. In operation, the oscillator 102 applies the OSC signal to clock the charge pump 106 which, in turn, develops the pumped voltage VCCP. The pumped voltage VCCP is fed back through the diode-coupled

20 transistor 110 and level shifting circuit 112 to develop the pump feedback voltage VPF. At this point, the current flowing through the diode-coupled transistor 116 as determined by the current source 118 develops the reference voltage VREF. As long as the pump feedback voltage VPF is less than the reference voltage VREF, the comparator drives the EN signal active, causing the oscillator 102 to clock the charge pump 106.

- 25 As the charge pump 106 operates, the pumped voltage VCCP increases to a point where the pumped voltage fed back through the diode-coupled transistor 110 and level shifting circuit 112 causes the pump feedback voltage VPF to exceed the reference voltage VREF. When the pump feedback voltage VPF is greater than the reference voltage

VREF, the Schmitt Trigger comparator 104 deactivates the EN signal causing the oscillator 102 to stop clocking the charge pump 106 which, in turn, turns OFF. The charge pump 106 remains OFF until the pumped voltage VCCP discharges through a load resistance 109 and drops to a value causing the pump feedback voltage VPF to once again become less than
 5 the reference voltage VREF. When this occurs, the Schmitt Trigger comparator 104 once again activates the EN signal causing the oscillator 102 to clock the charge pump 106, which turns ON to once again begin charging the pumped output voltage VCCP.

When the supply voltage VCC increases, the overvoltage detector 120, current limiting circuit 126, and clamping circuit 128 operate in combination to limit the
 10 value of the pumped voltage VCCP. As the supply voltage VCC increases, the reference voltage VREF likewise increases, meaning that the pumped voltage VCCP similarly increases to thereby increase the feedback voltage VPF until it equals the increased reference voltage. When the supply voltage VCC exceeds a predetermined value, the overvoltage detector 120 activates the overvoltage signal OV, turning ON the transistors
 15 122 and 130. When the transistor 130 turns ON, the pumped voltage VCCP is limited to a value above the supply voltage VCC determined by a small voltage drop across the transistor 130 plus the voltage drop across the diode-coupled transistor 132. Similarly, the turned ON transistor 122 and current source 124 attempt to sink current in parallel with the current source 118 to increase the voltage across transistor 116 and thereby limit the
 20 increase in the value of the reference voltage VREF. Ideally, the reference voltage VREF tracks the supply voltage VCC until the supply voltage exceeds the predetermined value which activates the overvoltage detector 120. This maintains a constant difference between the supply voltage VCC and the pumped voltage VCCP until the supply voltage exceeds the predetermined value. Ideally, once the supply voltage VCC exceeds the predetermined
 25 value, the reference voltage VREF is held constant, causing the pumped feedback voltage VPF to become greater than the reference voltage, which causes the Schmitt Trigger comparator 104 to deactivate the EN signal to thereby deactivate the oscillator 102 and turn

OFF the charge pump 106. As will now be explained in more detail, the voltage generation circuit 100 does not, however, operate in this ideal manner.

The supply voltage VCC may increase, for example, during burn-in of an integrated circuit containing the voltage generation circuit 100. Typically, during burn-in
5 the supply voltage VCC is increased to stress components contained within the integrated circuit, as will be understood by those skilled in the art. Figure 2 is a graph illustrating the values of the pumped voltage VCCP, reference voltage VREF, and the overvoltage signal OV in the voltage generation circuit 100 as the supply voltage VCC increases. In the example of Figure 2, the values of the supply voltage VCC and pumped voltage VCCP are
10 initially two and three volts, respectively. At a time T1, the supply voltage VCC begins to increase and the pumped voltage VCCP and reference voltage VREF similarly begin increasing as illustrated. At this point, the overvoltage detector 120 is monitoring the supply voltage VCC but has not activated the overvoltage signal OV. Until a time T2, the reference voltage VREF tracks the supply voltage VCC to maintain a constant difference
15 between the supply voltage and the pumped voltage VCCP. At the time T2, the overvoltage signal OV goes active, turning ON the current limiting circuit 126 and clamping circuit 128. Notwithstanding the activation of the circuits 126, 128, it is seen that the pumped voltage VCCP and the reference voltage VREF continue increasing after the time T2. This is true because due to physical limitations, such as heat dissipation and size
20 limitations when forming components of the current source 124, the current limiting circuit 126 cannot sink enough current to limit the value of the reference voltage VREF as the supply voltage VCC increases. As a result, as the supply voltage VCC increases the pumped voltage VCCP and reference voltage VREF likewise increase.

In the voltage generation circuit 100, the pumped voltage VCCP may
25 become so great as the supply voltage VCC increases that components of the integrated circuit containing the voltage generation circuit may be damaged. For example, the pumped voltage VCCP may exceed the breakdown voltages of various devices such as MOS transistors formed within the integrated circuit. Moreover, it should be noted that the

clamping circuit 128 must dissipate what may be significant amounts of power as the pumped voltage VCCP increases and thus the voltage generation circuit 100 consumes wasted power and generates unwanted heat during the burn-in process.

There is a need for a voltage generation circuit that reliably limits the value of the pumped voltage as the supply voltage increases.

SUMMARY OF THE INVENTION

A method and circuit control the value of generated voltage derived from a supply voltage as the value of the supply voltage varies, such as during burn-in of an integrated circuit. According to one aspect of the present invention, a voltage generation circuit includes a generator circuit that receives a supply voltage and has a reference node. The generator circuit develops an output voltage from the supply voltage and the output voltage has a value that is a function of a reference voltage applied on the reference node. A coupling circuit is coupled to the reference node and also receives the supply voltage. The coupling circuit operates in response to a voltage control signal to vary an electronic coupling of the supply voltage to the reference node which thereby adjusts the value of the reference voltage. A voltage sensing circuit receives the reference voltage and develops the voltage control signal that is applied to the coupling circuit in response to the reference voltage. The coupling circuit controls coupling of the supply voltage to the reference node, adjusting the value of the reference voltage to control the output voltage of the voltage generation circuit.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a functional block diagram and schematic illustrating a conventional voltage generation circuit.

Figure 2 is a graph illustrating the effect of an increasing supply voltage on an output voltage and several other signals in the voltage generation circuit of Figure 1.

Figure 3 is a functional block diagram and schematic of a voltage generation circuit according to one embodiment of the present invention.

Figure 4 is a graph illustrating the effect of an increasing supply voltage on an output voltage and several other signals in the voltage generation circuit of Figure 3.

5 Figure 5 is a functional block diagram of a memory device including the voltage generation circuit of Figure 3.

Figure 6 is a functional block diagram of a computer system including the memory device of Figure 5.

DETAILED DESCRIPTION OF THE INVENTION

10 Figure 3 is a functional block diagram and schematic of a voltage generation circuit 300 according to one embodiment of the present invention. The voltage generation circuit 300 limits the value of a generated pumped voltage VCCP as an applied supply voltage VCC increases so that components within an integrated circuit containing the voltage generation circuit are not damaged, as will be explained in more detail below. In
15 the following description, certain details are set forth to provide a sufficient understanding of the invention. However, it will be clear to one skilled in the art that the invention may be practiced without these particular details. In other instances, well-known circuits, control signals, timing protocols, and software operations have not been shown in detail in order to avoid unnecessarily obscuring the invention.

20 The voltage generation circuit 300 includes a Schmitt Trigger comparator 302, oscillator 304, and charge pump circuit 306, which operate in the same manner as previously described for the corresponding components in the voltage generation circuit 100 of Figure 1. For the sake of brevity, these components will not again be described in detail. A more detailed description of a charge pump circuit is provided in U.S. Patent No.
25 6,160,723 to Liu entitled "Charge Pump Circuit Including Level Shifters for Threshold Voltage Cancellation and Clock Signals Boosting, and Memory Device Using Same," and in U.S. Patent Application No. 09/256,972 to Liu entitled "Method and Circuit for

Regulating the Output Voltage from a Charge Pump Circuit, and Memory Device Using Same" filed on 24 February 1999, both of which are incorporated herein by reference.

A diode-coupled PMOS transistor 308 and current source 310 develop a control signal 312. The control signal 312 is applied to a gate of an NMOS transistor 314 that is coupled in series with a current source 316 between the supply voltage VCC and ground, and the transistor 314 develops a pump feedback voltage VPF in response to the control signal. The pump feedback voltage VPF is applied to one input of the Schmitt Trigger comparator 302. A coupling circuit 315 is formed by a diode-coupled PMOS transistor 317, an NMOS transistor 318, and a current source 320, which operate in combination to develop a reference voltage VREF in response to an overvoltage control signal OVC, with the reference voltage being applied to a second input of the Schmitt Trigger comparator 302. In response to the OVC signal, the transistor 318 adjusts the current through the diode-coupled transistor 317 to control the value of the reference voltage VREF.

The diode-coupled transistors 308 and 317 are matched, as are the current sources 310 and 320, which provides common-mode level shifting of the pump feedback voltage VPF and reference voltage VREF. In the embodiment of Figure 3, the transistor 314 is a long-channel device that develops a voltage between control signal 312 and voltage VPF of about 1.5 volts, which determines the difference between the supply voltage VCC and pumped voltage VCCP, as will be appreciated by those skilled in the art.

A voltage sensing circuit 322 develops the OVC signal in response to the reference voltage VREF. The voltage sensing circuit 322 includes an NMOS transistor 324, a diode-coupled NMOS transistor 326, and a current source 328 that operate in combination to develop a control signal 330 in response to the reference voltage VREF. More specifically, the transistor 324 adjusts the current through the diode-coupled transistor 326 in response to the reference voltage VREF to control the value of the control signal 330. The control signal 330 is applied to a gate of an NMOS transistor 332 that is coupled in series with a current source 334 between the supply voltage VCC and ground.

In response to the control signal 330, the transistor 332 controls the value of the OVC signal applied to the transistor 318. Thus, the voltage sensing circuit 322 forms a feedback circuit that adjusts the value of the OVC signal in response to the reference voltage VREF to and thereby control the value of the reference voltage.

5 During normal operation of the voltage generation circuit 300, the oscillator 304 clocks the charge pump 306 which, in turn, charges a load capacitor 336 to develop the pumped voltage VCCP across the load capacitor. In response to the pumped voltage VCCP, the diode-coupled transistor 308 and current source 310 develop the control signal 312 that is applied to the transistor 314 which, in turn, develops the pump feedback voltage
10 VPF applied to the Schmitt Trigger comparator 302. At the same time, the coupling circuit 315 and voltage sensing circuit 322 operate combination to develop the voltage reference VREF that is applied to the Schmitt Trigger comparator 302. During normal operation, the transistor 332 is turned OFF, causing the OVC signal to go to approximately the supply voltage VCC and turning ON the transistor 318. In this situation, the value of the reference
15 voltage VREF is determined by a small voltage drop (less than the threshold voltage of the transistor 332) across the current source 328 plus the voltage drop across the diode-coupled transistor 326 plus the threshold voltage of the transistor 324.

In the normal operation mode, as long as the pump feedback voltage VPF is less than the reference voltage VREF, the Schmitt Trigger comparator 302 enables the
20 oscillator 304 which, in turn, clocks the charge pump 306 so that the charge pump continues charging the capacitor 336 to increase the value of the pumped voltage VCCP. When the pumped voltage VCCP reaches a value causing the pump feedback voltage VPF to become greater than the reference voltage VREF, the Schmitt Trigger comparator 302 disables the oscillator 304 which, in turn, stops clocking the charge pump 306. At this
25 point, capacitor 336 begins to discharge through a load resistance 337. When the voltage VPF once again becomes less than the reference voltage VREF the Schmitt Trigger comparator 302 activates the oscillator 304 to clock the charge pump 306 to charge the load capacitor 336 and increase the pumped voltage VCCP.

The operation of the voltage generation circuit 300 in an overvoltage mode, which occurs when the supply voltage VCC increases such as may occur during burn-in of an integrated circuit (not shown) containing the voltage generation circuit, will now be explained in more detail with reference to Figures 3 and 4. Figure 4 illustrates the values for the pumped voltage VCCP, the supply voltage VCC, the overvoltage control signal OVC, the reference voltage VREF, and the control signal 330 during operation of the voltage generation circuit 300 in the overvoltage mode. Although not shown in Figure 4 to simplify the figure, the pumped voltage VCCP has ripple due to the hysteresis of the Schmitt Trigger comparator 302. As will now be explained in more detail, during the overvoltage mode the coupling circuit 315 and voltage sensing circuit 322 operate in combination to limit the value of the pumped voltage VCCP. More specifically, as the supply voltage VCC increases, the voltage on the gate and drain of the diode-coupled transistor 317 increases, and this increased voltage is applied through the transistor 318 to increase the reference voltage VREF. In response to the increased reference voltage VREF, the Schmitt Trigger comparator 302 activates the oscillator 304 which, in turn, causes the charge pump 306 to increase the pumped voltage VCCP until the pump feedback voltage VPF once again equals the increased reference voltage. In Figure 4, at a time a T0 the supply voltage VCC begins increasing and the pumped voltage VCCP and reference voltage VREF likewise increase in response to the increasing supply voltage.

At a time a T1, the control signal 330 begins increasing from a value of approximately zero volts in response to the increasing reference voltage VREF and corresponding increase in current through the transistor 324, diode-coupled transistor 326, and current source 328. At this point, note that the overvoltage control signal OVC also increases and approximately equals the supply voltage VCC since the transistor 332 is turned OFF. The control signal 330 continues increasing along with the other signals until a time T2, when the magnitude of the control signal equals approximately the threshold voltage of the transistor 332. In response to the control signal 330, the transistor 332 turns ON at the time T2, causing current to flow through the current source 334 and the transistor

and controlling the value of the overvoltage control signal OVC as illustrated in Figure 4. When the value of the overvoltage signal OVC is limited at the time T2, the value of the reference voltage VREF is limited to the sum of the threshold voltages of transistors 324, 326, and 332. As a result, the increases in the supply voltage VCC no longer increase the reference voltage VREF. After the time T2, the pumped voltage VCCP no longer increases and is thus limited to prevent damage to components (not shown) in the integrated circuit (not shown) containing the voltage generation circuit 300. Moreover, the power consumption of the charge pump 306 does not increase after the time T2 notwithstanding further increases in the supply voltage VCC.

Figure 5 is a block diagram of a memory device 500 including the voltage generation circuit 300 of Figure 3. The voltage generation circuit 300 applies the pumped voltage VCCP to a memory-cell array 502 contained in the memory device 500, and may also apply the pumped voltage to other components in the memory device. In the memory-cell array 502, the pumped voltage VCCP is applied, for example, to word lines (not shown) to access corresponding rows of memory cells (not shown), as will be understood by those skilled in the art. The memory device 500 further includes an address decoder 504, a control circuit 506, and read/write circuitry 508, all of which are conventional and known in the art. The address decoder 504, control circuit 506, and read/write circuitry 508 are all coupled to the memory-cell array 502. In addition, the address decoder 504 is coupled to an address bus, the control circuit 506 is coupled to a control bus, and the read/write circuitry 508 is coupled to a data bus.

In operation, external circuitry (not shown) provides address, control, and data signals on the respective busses to the memory device 500. During a read cycle, the external circuitry provides a memory address on the address bus and control signals on the control bus. In response to the memory address on the address bus, the address decoder 504 provides a decoded memory address to the memory-cell array 502 while the control circuit 506 provides control signals to the memory-cell array in response to the control signals on the control bus. The control signals from the control circuit 506 control the

memory-cell array 502 to provide data to the read/write circuitry 508. The read/write circuitry 508 then provides this data on the data bus for use by the external circuitry. During a write cycle, the external circuitry provides a memory address on the address bus, control signals on the control bus, and data on the data bus. Once again, the address
5 decoder 504 decodes the memory address on the address bus and provides a decoded address to the memory-cell array 502. The read/write circuitry 508 provides the data on the data bus to the memory-cell array 502 and this data is stored in the addressed memory cells in the memory-cell array under control of the control signals from the control circuit 506. The memory device 500 may be a dynamic random access memory (DRAM), synchronous
10 DRAM (SDRAM), double-data-rate (DDR) DRAM, packetized memory device such as an SDRAM or RAMBUS device, or other type of memory device as well. Moreover, the voltage generation circuit 300 may be placed integrated circuits other than memory devices.

Figure 6 is a block diagram of a computer system 600 which uses the memory device 500 of Figure 5. The computer system 600 includes computer circuitry 602
15 for performing various computing functions, such as executing specific software to perform specific calculations or tasks. In addition, the computer system 600 includes one or more input devices 604, such as a keyboard or a mouse, coupled to the computer circuitry 602 to allow an operator to interface with the computer system. Typically, the computer system 600 also includes one or more output devices 606 coupled to the computer circuitry 602,
20 such output devices typically being a printer or a video terminal. One or more data storage devices 608 are also typically coupled to the computer circuitry 602 to store data or retrieve data from external storage media (not shown). Examples of typical data storage devices 608 include hard and floppy disks, tape cassettes, and compact disk read only memories (CD-ROMs). The computer circuitry 602 is typically coupled to the memory
25 device 500 through a control bus, a data bus, and an address bus to provide for writing data to and reading data from the memory device.

It is to be understood that even though various embodiments and advantages of the present invention have been set forth in the foregoing description, the above

disclosure is illustrative only, and changes may be made in detail, and yet remain within the broad principles of the invention. For example, some of the components described above may be implemented using either digital or analog circuitry, or a combination of both, and also, where appropriate, may be realized through software executing on suitable processing
5 circuitry. Also, the conductivity types of the devices, such as NMOS and PMOS transistors, may also be varied as required by particular applications, as will be understood by those skilled in the art. Therefore, the present invention is to be limited only by the appended claims.